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Simulated Impact of Non-Linear Memory Effects on Digital Communications in a Klystron

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Abstract: *The results of passing digital communications signals through a 1-D physics-based klystron model are presented and compared to the series block model. Non-linear memory effects are shown to be important at high data rates near saturation.*

Keywords: klystron; distortion; nonlinearity

Introduction

System-level simulations of transmitters for communications applications typically employ a series block model to describe the response of the amplifier. Such a model consists of a linear, frequency-dependent block to describe the complex frequency response, cascaded with a nonlinear, frequency-independent block to account for the saturation effects on amplitude and phase. Such models are generally adequate for modeling the behavior of digital communication signals passing through the amplifier when the data rate and the nonlinearity are not simultaneously large. They are also closely linked to the typical frequency response curves and AM-AM and AM-PM specifications traditionally used in designing systems with vacuum electronic amplifiers.

Klystrons are widely used in communication applications, for ground-based links and satellite uplinks. The nearly saturated condition in klystrons is desired for high efficiency, and the use of multiple phase-shift-keying (m-PSK) between equal amplitude digital symbols avoids the most obvious problems with nonlinearity. However, nonlinear memory effects, which cannot be described by the series block model nor by conventional AM-AM or AM-PM specifications, can occur in klystrons operated near saturation under high data rate conditions. They arise from the combination of energy storage in the output cavity and nonlinear deceleration of the electron bunches. Such effects will lead to excessive system bit error rates unless they are properly modeled and accounted for in the system design.

Results

To study this issue, simplified 1-dimensional, time-dependent simulations of a two-cavity klystron with a tapered-charge disk model for the electron beam were performed under a variety of modulations of the carrier signal. This physics-based model assumes a memoryless

input gap, ballistic bunching in the inter-cavity drift tube, and a 14.3 GHz resonant output cavity. It was anticipated that a simplified model would allow the most fundamental causes of memory effects to be easily identified and understood, without confusion from higher-order effects obtainable in multi-dimensional field-theory or three-dimensional particle-in-cell simulations. The simplified

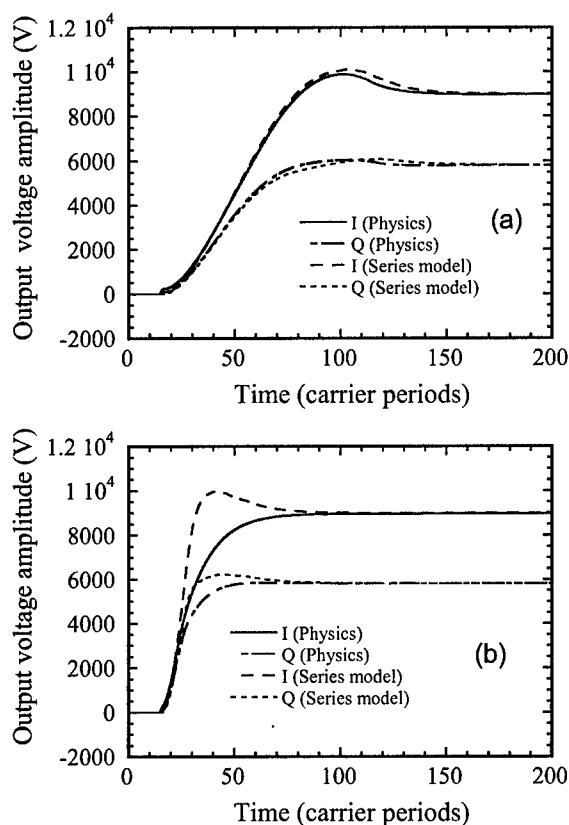


Figure 1. Comparison of the physics-based and the series model for a klystron under (a) slow and (b) fast amplitude transition rates when driven over the saturation point. Envelopes of the in-phase (I) and quadrature-phase (Q) components are shown after demodulation.

disk model also allows for rapid simulations with only about 2000 state variables. Transient responses of the klystron under step and rate-controlled ramp envelope modulations were computed. Significant changes in the functional form of the transient response (compared to the block models) occurred at high transition rates when the modulating signal was allowed to cross the saturation point, as shown in Fig. 1. At the highest rates, the klystron can "tunnel" directly from an unsaturated to an over-saturated condition, without ever producing the peak in output power

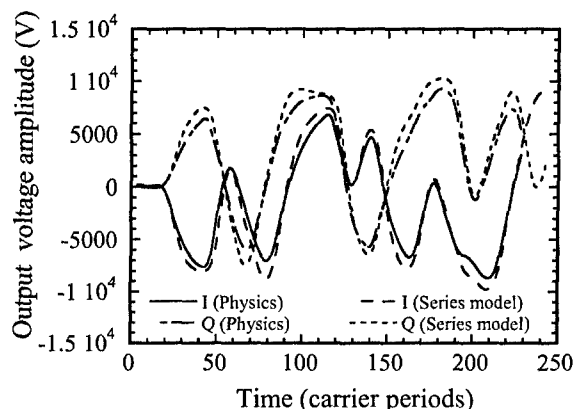


Figure 2. Comparison of physics and series models under high data rate 4-PSK modulation at saturation.

level that occurs at saturation under CW conditions. The detailed causes of this behavior in terms of electron bunching and cavity fields will be described.

In addition, phase modulated waveforms corresponding to m-PSK digital signals with raised cosine symbols were passed through the physics model to study nonlinear memory effects and their impact on signal integrity. Examples are shown in Figs. 2 and 3. Although the series block model performed very well at slow data rates

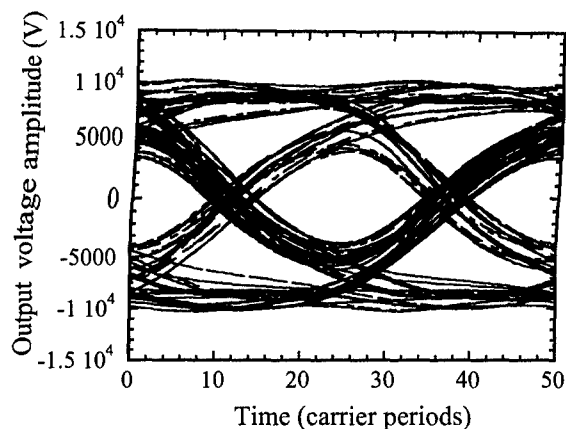


Figure 3. Eye diagram from the physics-based model for 4-PSK modulation at saturation with a data rate comparable to the klystron bandwidth

compared to the bandwidth (regardless of amplitude) significant time-domain distortions and resulting symbol error rates were found when high data rates were applied under saturated conditions. The use of a simple cascaded linearizer/equalizer to improve symbol error rate was investigated. While improvement was noted, significant errors still occur.

Conclusions

The simulation studies point out the need for physics-based models, or hybrid block/physics models, for use in system design in critical applications. Such models could be applied to help devise new methods of direct digital pre-distortion, as well as to new concepts for analog linearizers and equalizers, that are more suited to the intrinsic nonlinear memory behavior of klystrons

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